# Quadriceps Tendon Allografts are Biomechanically Equivalent to Achilles Tendon Allografts

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## Abstract

Quadriceps tendon with a patellar bone block may be a viable alternative to Achilles tendon for anterior cruciate ligament reconstruction (ACL-R) if it is, at a minimum, a biomechanically equivalent graft. The objective of this study was to directly compare the biomechanical properties of quadriceps tendon grafts to Achilles tendon grafts. Quadriceps and Achilles tendon pairs from nine donors (nine males, mean age 56.9 years, range 37-74 years) were tested in a physiologic environmental chamber under sub-failure and failure loading regimes. The results showed that there were no statistical differences in seven of eight structural and mechanical properties (maximum load, stiffness, maximum stress, maximum strain, strain at maximum stress, modulus of elasticity and cyclic elongation) between the two tendon types. The significantly higher displacement at maximum load observed for quadriceps tendons may be related to the failure mode. While specimens failed either by bone avulsion or rupturing of the tendon mid-substance, Achilles tendons had a higher avulsion rate than the quadriceps tendons (89% compared to 22%, respectively). This was likely due to observed differences in bone block density between the two tendon types. This research supports the use of quadriceps tendon allografts in lieu of Achilles tendon allografts for ACL-R.

## Introduction

Anterior cruciate ligament (ACL) ruptures occur at an estimated rate of 1 in 3000, resulting in approximately 100,000 ACL reconstructions (ACL-R) performed in the United States annually[1]. ACL injuries can be treated by reconstructing the damaged ligament with a variety of soft tissue allografts[2], and allografts with bone blocks are particularly popular because the bony attachment can provide better fixation and healing within the bone tunnels. Patellar and Achilles tendons are the most common tendon-bone allografts used for ACL-R[3], but quadriceps tendons may provide a viable alternative.

Quadriceps tendon use for ACL-R was first reported in the 1980s[4], and more recent studies have shown that quadriceps autografts yield clinical outcomes equivalent to those of patellar tendon autografts[5]. While quadriceps autograft use appears to be increasing, comparable interest in quadriceps allografts has not been observed. A lack of information regarding quadriceps allograft biomechanical properties and clinical outcomes may be a factor. Although such comparisons of Achilles or quadriceps tendons to other tendons such as BTBs are documented in the scientific literature, to our knowledge there has not been a direct comparison of Achilles and quadriceps tendons prepared using traditional tissue banking processes and terminal sterilization. Therefore, to promote the use of quadriceps tendon allografts as an alternative to Achilles grafts for ACL-R we performed a direct biomechanical comparison of the two graft types.

## Study Objective

The purpose of this study was to compare the biomechanical properties of aseptically prepared, terminally sterilized quadriceps tendon with bone to Achilles tendon with bone. Our hypothesis was that the structural and material properties of quadriceps tendons would not be significantly different from those of Achilles tendons.

## Specimen Preparation

Paired Achilles tendons with bone blocks and quadriceps tendons with bone blocks were procured from nine research-consented donors (nine males, mean age 56.9 years, range 37-74 years) and aseptically processed using current procedures. All specimens were terminally sterilized via low-dose gamma irradiation. Tendons were stored at ≤-65°C and then thawed in a 37°C water bath for no more than 15 minutes prior to testing.

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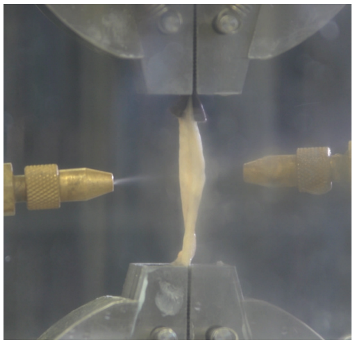
For both tendon types, the central 10 mm of the bone-tendon complex was isolated[6]. Quadriceps tendons were further trimmed by sharp dissection to isolate the tightly connected bundles of the rectus femoris and the vastus intermedius[7]. All bone blocks were potted in Bondo® body filler to increase the grip surface to prevent slippage.

## Biomechanical Testing

Tendon cross sectional area was measured in an unloaded state using digital micrometers. The specimen was then placed in an environmental testing chamber that maintained a physiologic temperature at 37±2°C and misted the specimen with saline for the testing duration. Specimens were secured in pneumatic grips and an initial gage length was measured between the top edges of each grip using a ruler. All specimens were gripped to maintain a consistent length-to-width ratio of approximately 5:1.


*Environmental testing chamber.*


*Specimen being misted with saline.*

Testing was performed using a materials testing system (ElectroPuls E3000; Instron, Norwood, MA). To mimic different physiologic loading scenarios, a three-phase uniaxial tension loading protocol was used that was comprised of a load-controlled sinusoidal waveform cycled between 0-200 N at a 2 Hz frequency for 2000 cycles, a five minute stationary rest for tendon recovery, and a ramp to failure at a displacement-controlled rate of 100% strain per second[8]. Failure mode was recorded.

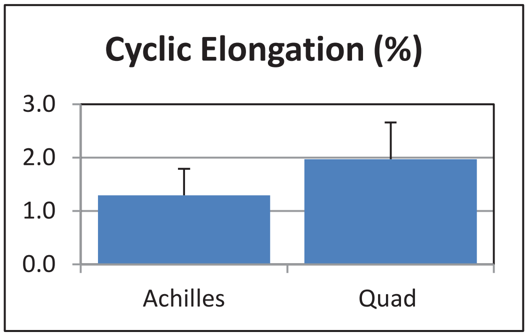
## Data Analysis

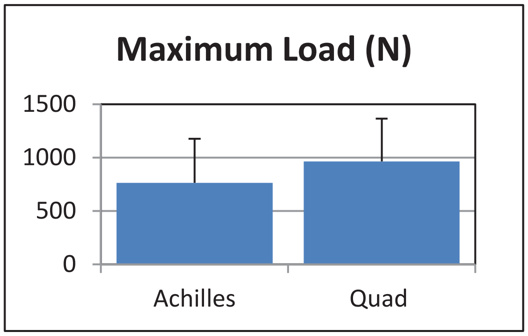
Structural and material properties were calculated from load-displacement and stress-strain curves, respectively. Maximum load and displacement at the maximum load were recorded, and stiffness was calculated as the linear portion of the load–displacement curve in the failure phase of testing. Stress was calculated as the force applied to the tendon divided by the measured cross sectional area. The maximum stress and the corresponding strain at maximum stress were reported. Failure strain was calculated by dividing displacement by the summation of the initial gage length plus the additional accrued length from the cyclic phase ($\Delta L/(L^{initial}+L^{additional})$). Modulus of elasticity was calculated as the linear portion of the stress-strain curve in the failure phase. Cyclic elongation of the tissue after the cyclic phase of testing was calculated as $((L^{2000} - L^{10})/L^{10})*100$.

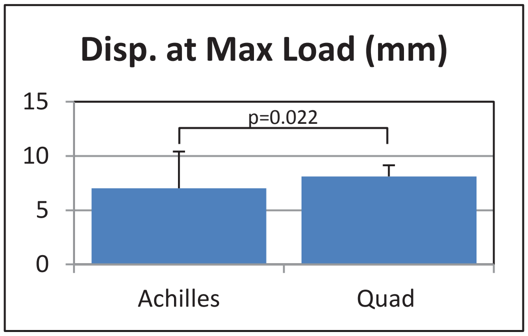
Mean and standard deviation were calculated for the maximum load, displacement at maximum load, stiffness, maximum stress, strain, strain at maximum stress, modulus of elasticity, and cyclic elongation for each tendon type. A paired t-test was used to detect significant differences between tendon types using statistical software. A difference was considered significant if the calculated p-value was less than a two-tailed $\alpha$ of 0.05.

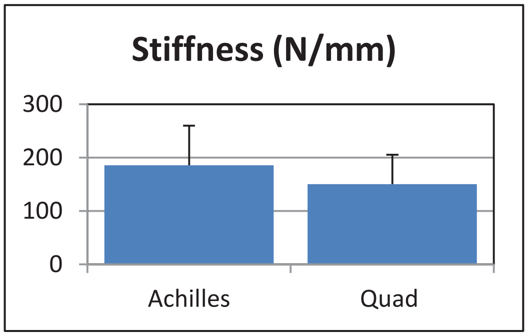
## Results

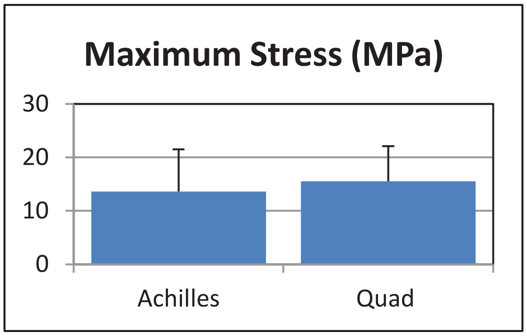
All specimens failed either by bone avulsion (eight Achilles and two quadriceps tendons) or tendon mid-substance rupture (one Achilles and seven quadriceps tendons). No slippage or failure at the grip was observed. Biomechanical results indicated that there were no significant differences in maximum load, stiffness, stress, maximum strain, strain at maximum stress, modulus of elasticity, and cyclic elongation between the quadriceps and Achilles tendons. Quadriceps tendon had significantly greater displacement at maximum load than Achilles tendons (p=0.022).

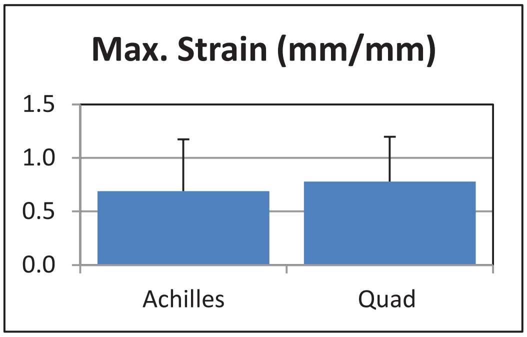


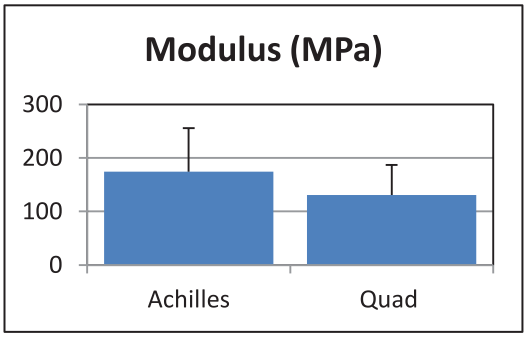












## Conclusions

This direct biomechanical comparison of quadriceps and Achilles tendon allografts showed no statistically significant differences in seven out of eight structural and material properties. The difference in displacement at maximum load may be attributable to density variations in the bony attachments of the two tendons, as the cancellous bone of the patella is generally thicker and more compact than that of the calcaneus. This may also explain a 22% bone avulsion rate for quadriceps tendons compared to an 89% avulsion rate for Achilles tendons, which suggests a strong patella-quadriceps tendon interface that shifted the failure initiation to the tendon. Our results also represent only two bundles of the quadriceps tendon. Should clinicians choose to utilize the entire tendon, the increased tissue mass could bolster its biomechanical capabilities. Based on our biomechanical results, we recommend quadriceps tendon allografts for use in ACL-R as an alternative to Achilles tendon allografts.

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